

Dichotic, Binaural, and Monaural NU-6 Word Recognition Performance
for Young and Older Adults

A Senior Honors Thesis

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ABSTRACT

Listening to a sound with two ears, or binaural listening, helps a listener to localize and understand the message better than with one ear alone. For some older adults with hearing loss, however, binaural listening proves to be disadvantageous, especially in situations with background noise (i.e., binaural interference). The present study examined binaural processing abilities for two subject groups: young adults with normal hearing (ages 18-30 years) and older adults with sensorineural hearing loss (ages 60-90 years). Two types of speech-recognition assessments were used: (1) word recognition in noise and (2) dichotic word recognition. For the word recognition in noise tasks, subjects responded under three conditions: (1) monaural left-ear, (2) monaural right-ear, and (3) binaural. For the dichotic listening tasks, subjects were given three response conditions: (1) free recall (repeat both stimuli in any order), (2) directed-recall right (repeat stimuli heard in right ear first), and (3) directed-recall left (repeat stimuli heard in left ear first). Results showed that both subject groups exhibited expected patterns of performance for both tasks. Specifically, both young and older adults performed better in the binaural condition than with either ear alone in the word recognition in noise task. For the dichotic listening task, older adult subjects showed a larger mean REA than young adults, and both groups showed increased ear advantages in each respective directed attention condition (i.e., directed right and directed left). Further, initial results suggest that recognition performance on both speech measures was poorer for the older adults with hearing loss than for the young adults with normal hearing. Past studies have shown that older adults with hearing loss and binaural interference may have more success using one hearing aid rather than two (Carter et al., 2001; Chmiel et al., 1997). The results of the present study therefore may prove to be significant in supporting future aural rehabilitation methods and research related to geriatric audiology.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

There are distinct physiological advantages related to having two ears as opposed to only one. Arguably the most important are the abilities to localize, better perceive, and better recognize sound. Because our ears are positioned on opposite sides of our head, we are provided with two different places for sound input. Sound waves will therefore arrive at one ear before the other, leading to what are known as interaural time differences. Interaural level differences also exist. Sound is attenuated as it travels from one place to another, therefore, a sound reaching the right ear after the left ear will be less intense because it travels a greater distance and is attenuated (or “shadowed”) by the head. Interaural time and level differences between our two ears are responsible for our ability to localize sound sources (Yost, 2007, p.173).

In addition to localization, listening to sounds with two ears also provides us with two other advantages: binaural summation and binaural squelch. For individuals with normal hearing and processing abilities, listening to a sound(s) with both ears, or binaural listening, is more advantageous than listening to a sound with one ear alone (monaurally). A sound attended to by both ears is perceived as being louder than when it is attended to either ear alone at a constant level. Thus, binaural listening results in a “summation effect.” Additionally, listening with two ears in a noisy environment can help in discriminating the desired signal from the unwanted background noise. This phenomenon is termed the “cocktail party effect,” or binaural squelch, and refers to the benefit of increased signal detection in competitive environments due to binaural listening (Yost, 2007, p. 185).

The total advantage of binaural listening can therefore be summed up in three components. Not every individual, however, possesses a binaural advantage. Certain individuals,

such as some older adults with sensorineural hearing loss, may have more difficulty using time and level differences to localize and understand sound, especially in competitive environments. Additionally, some studies have shown that listening to speech binaurally can actually be a disadvantage for some individuals, and monaural listening may in fact produce better speech recognition (Allen, Schwab, Cranford, & Carpenter, 2000; Jerger, Silman, Lew, & Chmiel, 1993). This phenomenon, known as binaural interference, involves one ear actually interfering with speech recognition for the other ear. For individuals experiencing binaural interference, monaural amplification may be a better rehabilitation strategy instead of traditional binaural hearing aid fittings.

We can find out more information regarding a person's binaural and monaural processing abilities by using certain listening tasks, namely word recognition in noise and dichotic listening tasks. Word recognition in noise tasks involve presenting a sound monaurally or diotically (same sound to both ears simultaneously) and measuring the subject's ability to recognize the word. Dichotic listening tasks, on the other hand, involve presenting two different sounds (one to the right ear, one to the left ear) simultaneously.

Recognition performance scores for older adults with symmetric sensorineural hearing loss are generally lower than younger individuals with normal hearing. For word recognition in noise scores, the binaural (diotic) condition usually results in better recognition than either monaural condition (as we should expect), and recognition scores for monaural conditions are generally the same for both ears. For dichotic listening tasks, however, a right ear advantage, or REA, is usually exhibited in most listeners (Bryden, 1988; Kimura, 1961), and this REA is usually more pronounced in older individuals with hearing loss (Wilson & Jaffe, 2003; Bryden, 1988).

The present study compared binaural and left- and right-ear monaural word recognition in noise (multitalker babble) with dichotic listening recognition scores. Scores were compared across two subject groups: young adults with normal hearing and older adults with symmetrical sensorineural hearing loss, all of whom were right-handed.

The Meaning and Importance of Binaural Listening

The phrase “hearing but not understanding” is a great starting point for the present study. There are chief physiological differences between simply detecting a sound and perceiving and understanding it. *Sensation*, or detection, describes the processing of basic properties of our physical surroundings (Yost, 2007). In the auditory system, the processing of a sound is performed by the hair cells of the cochlea transducing the auditory signal, the nervous system relaying the information to the brain, and the brain processing these basic sensations (i.e., processing the loudness of a sound).

Perception, however, differs from sensation in that it is more complex and requires additional processing of the sensory information. To derive true, real-world meaning from a sound, the auditory system must analyze the sensory information further using compound abilities, such as memory and attention. The end result, then, is our ability to use the sound meaningfully, whether it is determining the source of the sound, perceiving speech, or forming thoughts or opinions about the sound. (Yost, 2007, p. 203-204). Speech perception is therefore a task that relies on components beyond sensation; it involves both peripheral and central auditory system integrity in order for accurate perception.

Accurate perception of speech varies with the type of listening condition. Human beings, for example, possess two ears for a reason. For most individuals, using both ears to hear a sound is better than using one ear. Haggard and Hall (1982) found that a stimulus presented only to one

ear, or monaurally, at suprathreshold level must be 6 to 10 dB more intense than when presented binaurally (to both ears) in order to be perceived as equally loud. In addition to this intensity gain, binaural listening provides time and distance cues from both ears, helping a listener to localize and understand the message better than he or she would with one ear alone (Dubno, Ahlstrom, & Horwitz, 2008). Grose (1996) points out that listening to a sound binaurally provides an advantage for the individual because spatial differences between two ears allow for discrete temporal and distance cues for each ear. Resultantly, the listener can process these separate cues and is able to spatially localize each signal.

The ability to localize sounds is especially important in difficult, competitive environments, such as a room with intense background noise. Binaural listening is advantageous for most listeners in noisy environments because level and time differences arriving at the two ears are able to be processed separately. Thus, the listener can more easily discriminate the meaningful message from the unwanted noise (Dubno et al., 2008).

Binaural Interference

For some populations such as older adults, binaural listening actually proves to be disadvantageous, especially in situations where noise competes with the signal. There is sufficient evidence to suggest that, as the auditory system ages, it becomes less efficient in separating speech signals from noise, or *binaural signal analysis* (Warren, Wagener, & Herman, 1978). Warren et al. suggest that this is due to the decreased ability of older adults to use interaural differences of time and amplitude to localize and separate the signal from the noise.

More recent studies have shown that older adults experiencing a binaural deficit coupled with hearing loss often see more benefit from listening with one ear than with both ears. In a four-subject study conducted by Carter, Noe, and Wilson (2001), listeners with an auditory-

based deficit gained little benefit from being binaurally aided than when being unaided in speech recognition tasks. Additionally, subjects exhibited greater benefits for speech recognition in the presence of noise when fit monaurally for a hearing aid and/or when using an FM system than when fit binaurally for hearing aids.

When being tested for speech recognition, some older adults display an auditory phenomenon in which the performance of the better ear is actually impaired by performance of the poorer ear. Termed *binaural interference*, it is estimated that roughly 8 to 10 percent of hearing aid users in the older adult population (60 years of age and older) experience this phenomenon (Jerger, Silman, Lew, & Chmiel, 1993). Jerger et al. investigated binaural interference in four older adults with symmetric hearing loss using aided speech recognition testing and electrophysiologic measures (middle latency auditory-evoked responses). The results showed that, for these individuals, performance for these tasks was better during monaural stimulation compared to binaural stimulation. For individuals like these, there is no binaural advantage, only a binaural *disadvantage*.

A study performed by Allen, Schwab, Cranford, and Carpenter (2000) examined the prevalence of the binaural interference phenomenon in young adults with normal hearing and older adults with normal hearing and hearing loss. Outcomes showed that the prevalence of binaural interference in the subject group agreed with that predicted by statistical chance: 2 of the 48 subjects (2 of the 12 older, hearing-impaired subjects) exhibited binaural interference in speech recognition testing under diotic conditions, despite having symmetrical hearing losses.

Chmiel, Jerger, Murphy, Pirozzolo, and Young (1997) also showed similar results in their case study of a 90-year old woman. Despite her symmetric peripheral thresholds, results showed that the subject benefitted the greatest from being aided monaurally in the right ear than from

binaurally or monaurally in the left ear. According to the research team, this benefit profile is best explained by an auditory processing deficit related to decreased interhemispheric transfer integrity in the brain – thus, the patient’s left ear deficit was interfering with her right ear ability because of decreased communication ability between the right and left hemispheres of the brain. Indeed, Bellis and Wilber (2001) affirm this claim. Their research showed that, for aging populations, structural changes in the corpus callosum lead to decreased interhemispheric transfer. This change, then, may play an important role in the communication difficulties exhibited by older adults – notably, speech recognition tasks in competitive environments.

Diotic versus Dichotic Listening

In order to better understand individual binaural processing ability beyond basic clinical audiometric testing, we use certain methods to specifically examine binaural abilities in different environments. To test binaural processing, two types of measures may be used: speech recognition in noise and dichotic listening. Dichotic listening tasks entail presenting *different* signals to each ear simultaneously: a stimulus to the left ear and a different stimulus to the right ear. Speech recognition in noise tasks are tested under the *diotic* condition, which refers to presenting the same speech stimulus to both ears simultaneously. Speech recognition in noise tasks also test each ear alone, or monaurally.

Speech recognition in noise tasks involve asking a subject to identify a speech stimulus in the presence of a background competitor. Often implemented as a competitor is multitalker babble, comprised of multiple speakers simultaneously emitting non-meaningful speech. Speech-recognition tasks can use numerical digits, words, or sentences as stimuli, but monosyllabic words seem to produce the best results (Wilson, 2003).

Word recognition in noise tasks can be tested in the right and left ears separately (monaural condition) or both ears at the same time (binaural diotic condition). As discussed previously, the binaural advantage observed for most individuals should therefore produce the best speech recognition scores compared to the monaural condition. Wilson et al. (2003) does point out, however, that this advantage is decreased in the presence of background noise for word recognition in noise tasks. In addition to noise and aural condition, age is also a contributor to performance. When compared to older adults with normal hearing and hearing loss, younger adults with normal hearing exhibit better performance scores for word recognition in noise under the diotic condition (Warren et al., 1978).

Dichotic Listening Tasks

Ear Advantage

A landmark study conducted by Kimura (1961) explored cerebral lateralization of verbal material presented to the auditory system and if certain variables affect this lateralization. Subjects with lesions on different parts of the brain were the focus of study and were classified as representing speech signals in either the left or right hemisphere. Digits were presented to the subjects via earphones, and results showed that subjects who represented speech in the left hemisphere performed better with signals to the right ear. Conversely, left-hemisphere dominant subjects more efficiently processed material presented to the right ear. Performance seemed to be independent of both the site of lesion and handedness for each subject, therefore Kimura concluded that contralateral auditory pathways (those neural pathways crossing from the right ear to the left hemisphere, and vice versa) are stronger than ipsilateral (same-side pathways).

Kimura's study was significant because it showed that, for the majority of people, signals presented to the right ear are recognized more accurately than signals presented to the left ear in

dichotic listening tasks. This phenomenon is known as the right ear-advantage (REA), and the REA for older adults is often considerably larger than what is exhibited by young adults. The REA is often seen as an indication of left-hemisphere language lateralization, and individuals possessing this lateralization tend to perform better when stimuli arrive in the right ear (Bryden, 1988). The reasoning behind this can be explained by the results of Kimura's study (1961): the strength of the contralateral pathways in the auditory system - the contralateral pathways are stronger and more developed than the ipsilateral pathways. Further, during dichotic listening, the ipsilateral pathways are suppressed. Thus, a signal arriving at the right ear will be perceived better in the left hemisphere than if it were presented to the left ear.

Age Effects

Most individuals lateralize language in the left hemisphere, and therefore most individuals exhibit a slight REA (Bryden, 1988). A more pronounced REA, or a large left-ear disadvantage, is often indicative of aging and decreased integrity of the corpus callosum and the central auditory system. Accordingly, older subjects with presbycusis exhibit markedly increased REAs when compared to their normal-hearing counterparts (Bellis & Wilber, 2001). Specifically, Bellis and Wilber showed that the integrity of the corpus callosum begins to decrease between the ages of 40 and 55, but does not continue to decrease after this period. Their study was comprehensive, focused on relating gender, age, and interhemispheric function and included a wide variety of age groups from age 20-75 years, all right-handed individuals. Three measures of interhemispheric integrity were conducted, including a dichotic digits listening task. Results of the dichotic listening task proved to support previous research: performance on the digits task decreased by age group, and subjects of all age groups exhibited an REA (that increased with age).

Grose (1996) dissects several studies relevant to binaural processing and examines them for commonalities related to the aging auditory system. The author notes that there exists a “spectrum of binaural tasks,” and different levels of processing show different aspects of binaural processing related to the aging auditory system. He orders the studies by processing level, with localization of sound being the “lower level” and dichotic speech recognition being the “higher level.” Of special interest is his examination of dichotic competition – specifically, Jerger and Jordan’s 1992 study. Grose notes that in this study, which examines performances of elderly presbycusis and young, normal-hearing individuals, both subject groups showed better performance for stimuli presented on their right side. The elderly group, however, exhibited a significantly higher overall benefit when stimuli were presented to their right side compared to the young adult group, and interaural differences in audiometric sensitivity played no factor in this increased advantage. Grose names this a “greater left-ear decline” and attributes it to decreased integrity of the highest levels of the neural pathway, a process associated with aging. By examining Grose’s argument, we can subsequently conclude that in dichotic competitive environments, both young and older adults will show a right-ear advantage, however, older adults will show a markedly increased advantage compared to the young adults.

A similar correlation between aging and increasing REA for dichotic listening is further demonstrated by Noffsinger, Martinez, and Andrews (1996), and Roup, Wiley, and Wilson (2006). Noffsinger et al. studied elderly subject performance for dichotic digits, sentences, and nonsense syllables, while Roup et al. compared three subject groups (young adults with normal hearing and older adults with bilateral sensorineural hearing loss) and their dichotic word recognition performances. Both of these studies exemplified that, when compared to young adults, older adults perform better when stimuli is presented to the right side as opposed to the

left side. Thus, these studies concluded that aging seems to accompany an increasing REA, especially in the presence of sensorineural hearing loss.

Stimulus Effects on Dichotic Listening

Stimuli used for dichotic listening tasks vary from study to study, and there are four categories of stimuli: digits, consonant vowels (CVs, otherwise known as nonsense syllables), words, or sentences. Noffsinger et al. (1996) compared three different kinds of dichotic stimuli: digits, sentences, and nonsense syllables. The study focused on older adults with sensorineural hearing loss living in a VA long-term care facility. Digits and sentences proved to be more easily recognized for the elderly subjects, while nonsense syllables, as expected, proved to be significantly more difficult, and remarkable lower performances were noted for the left ear. Due to the remarkable difficulty with nonsense syllables, Noffsinger et al. concluded that, as stimuli become more meaningless for an individual, they become more difficult for recognition in dichotic listening. Conversely, as stimuli increase in their meaning, they also increase in their ability to be recognized. Furthermore, the researchers reasoned that duration of stimuli also affects recognition; CVs only last for a short duration, and because all CVs last for a similar duration, this causes them to be more troublesome in dichotic recognition.

Roup et al. (2006) notes that, “the difficulty of the dichotic listening task is dependent upon the type of stimuli presented,” (p. 231). When compared to broadband noise (which provides little interference in recognition) or nonsense syllables (which provide the most difficulty), the use of monosyllabic words (i.e., the Northwestern University Auditory Test No. 6, or NU-6) presents a favorable medium between these two stimuli and provides certain advantages for dichotic listening tasks. In addition to existing on a median difficulty level (neither too simple nor too difficult), monosyllabic words are in widespread use and are easily

available in standardized form. Moreover, there is normative data readily available from multiple studies that have used such lists. This allows for easier comparison of dichotic listening across studies.

Strategy Effects (Response Condition)

During a dichotic listening task, different response conditions can be implemented. The experimenter does this by altering the way in which he/she instructs a subject to respond. The subject can be given three different response conditions: free-recall, directed-attention right, and directed-attention left. In the free-recall condition, subjects are asked to recall the stimuli presented to both ears in any order. In the directed-recall conditions, the listeners are cued – in other words, they are instructed to recall stimuli presented to their right ear, followed by their left ear (and vice versa). The directed-attention response conditions therefore offer a strategy to the subject – a way of handling the auditory information. The free-recall condition (often given first if used in dichotic testing) offers no strategy to the subject, and can therefore be more challenging.

Roup et al. (2006) examines the effects of these different strategies used in dichotic listening. One-hundred word pairs were used in the study and, as expected, performance depended on response condition. A large advantage occurred in the ear that was directed respective to the response condition (a large REA for all groups in directed-attention right, a left ear advantage [LEA] for directed-attention left), and the majority of subjects exhibited an REA for free-recall. However, the young adult subject group performed better overall and within each condition than the older subjects. It is important to note that the older adults did perform particularly better in the directed-attention conditions compared to the free-recall conditions.

The results of the study are consistent with previous research findings in related studies (Wilson et al., 1968; Strouse et al., 2000). The fact that the older subjects possessed decreased performance in free-recall compared to directed-attention is revealing. Roup et al. explains that, by providing a strategy in the directed-recall condition, the listener is provided a means of directing attention to the stimuli and concentrating a certain way. In other words, the cognitive load is decreased, and therefore recognition performance tends to improve for most subjects. In the free-recall condition, no strategy is provided for recognizing the stimuli, and as a result subjects experience an increased cognitive load. The effects of aging on dichotic speech recognition increase this load for older subjects, generally resulting in poorer performances.

Sex Differences

According to Bryden (1988), research in neuropsychology generally purports that men tend to be more lateralized than women. Regarding dichotic listening, however, research tends to be more variable and less certain about sex-related tendencies and performances. Studies by Bryden (1979) and Hiscock and MacKay (1985) report data showing that men tend to have slightly higher REAs compared to women. The data do communicate, however, that although there are sex-related differences in dichotic listening tasks, these differences are only slight and of minor significance.

Bellis and Wilber (2001), as discussed earlier, focused on relating gender, age, and interhemispheric function, including age groups from age 20-75 years, all of whom were right-handed. For the dichotic listening task, men exhibited a larger REA than women for the 35-40 and 70-75 age groups, but results showed the opposite trend for the 20-25 and 55-60 age groups. Further, this study showed that men and women differ in the *aging of their corpus callosum* – it could be concluded that, based on their REAs related to age group, men and women perform

better with dichotic tasks at different stages in life. This may explain the variability in earlier studies when examining sex-related differences in dichotic listening performance.

The Effect of Handedness

The results of Kimura's 1961 study relating cerebral dominance and verbal stimuli were analyzed to investigate the presence of a relationship between handedness and ear advantage. Based on the subjects in the study, Kimura found handedness *not* to be a factor in dichotic performance. When analyzing subject groups by speech-recognition ear dominance and right/left-handedness, the results failed to be calculated for statistical significance; thus, Kimura concluded that handedness was not a factor for producing ear advantages in dichotic listening.

Recent studies conflict with this finding, however. Bryden (1988) states, "it is clear that the general pattern is that a far higher proportion of right-handers than of left-handers show an REA," (p.19). Specifically, Bryden lists an 82% occurrence of an REA in right-handers and only a 64% REA occurrence in left-handers based on results from 18 different studies. Based on the data provided by Bryden, it can be understood that right-handers tend to be more lateralized than left-handers regarding tasks of dichotic listening.

Similarly, Wilson and Leigh (1996) focused on the association between ear advantage and handedness. Focused on a population under 60 years of age, the study evaluated an equal number of right-handers and left-handers for dichotic CV performance. Right-handed subjects exhibited a strong REA, as expected, and left-handers also exhibited an overall REA, but left-handers *showed more variability* in their responses and a significantly smaller REA compared to right-handed subjects. Further, there were three response paradigms: simultaneous onsets, 90-millisecond right-ear lag, and 90-millisecond left-ear lag. Both subject groups performed better on materials presented to the right ear than the left ear for all three paradigms, but left-handers

exhibited this advantage only slightly. These results are consistent with previous related research (Gelfand, Hofman, Waltzman, & Piper, 1980; Noffsinger, 1985). Moreover, Wilson and Leigh concluded that overall performance by right- and left-handers differed for stimuli presented to the right ear, but did not differ when stimuli was presented to the left ear.

Clinical Implications and “Real-World” Significance

Research on speech recognition in noise and dichotic listening are important for numerous clinical reasons. Those seeking an audiologist to obtain better hearing are generally not concerned about improving their ability to hear simple tones or environmental sounds. On the contrary, they are interested in improving their ability to recognize and perceive speech (“real-world” functioning), therefore, research on speech recognition is vital to the clinical realm of audiology.

The decision of whether to fit an individual with binaural or monaural hearing aids is a current key issue in clinical audiology. As multiple research suggests, some clients have better listening experiences when wearing one hearing aid as opposed to the conventionally-prescribed two (Carter et al., 2001; Chmiel et al., 1997; Jerger et al., 1993). These individuals often exhibit the phenomenon of binaural interference, in which the performance of the better ear is interfered by the performance of the poorer ear despite symmetrical hearing sensitivity (see previous discussion, *Binaural Interference*).

To further investigate the issue of binaural versus monaural hearing aid success, Brooks (1984) investigated subjective ratings of binaural and monaural amplification modes. Additionally, the study compared ratings of these amplification modes to the results of individuals with normal hearing. Subjects were given an evaluation form listing ten different hypothetical listening situations, and they were asked to rate each situation on a five-point scale.

Results showed that, in situations where the signal-to-noise ratio is rather low (i.e., a noisy restaurant), binaural hearing aid users gave a rating well below that of a normal hearing person and had no real advantage over monaural hearing aid users. In situations where the signal-to-noise ratio is high, however (i.e., a one-on-one conversation in quiet), binaural hearing aid users generally tended to give the same ratings as normal-hearing individuals. In these situations the binaural users also gave ratings above monaural users, showing evidence for the various benefits of binaural fittings.

Although the methodology of this study was performed on a subjective basis, it is valuable in that it gives support to objective studies showing the different characteristics of the binaural condition: beneficial in quiet environments and seemingly lacking benefits in competing environments. It is distinctively revealing because it draws from the perspective of the subjects rather than simply their responses to stimuli and a researcher's conclusion based on this stimuli. Because clinical audiology is clientele-based, subjective opinions of the client should be held with upmost respect and importance; it is the client's real-world experience that matters and not their performances on a clinical test. Research on speech recognition, such as the present study, aims to assist in bettering this "real-world" experience by exploring problems and finding applicable solutions.

Present Study

The aim of the present study was to assess differences (if any) of binaural processing abilities among young adults with normal hearing and older adults with sensorineural hearing loss. To assess binaural processing ability, two types of listening tasks were used: (1) binaural diotic, left monaural, and right monaural word recognition in multitalker babble and (2) free- and directed-recall dichotic listening tasks. Younger adults were hypothesized to exhibit a slight

REA for the dichotic listening tasks, and older adults were expected to exhibit a more pronounced REA. The present study asks two main questions: (1) When examining word-recognition performances of young and older adults, what is the relationship between dichotic listening and left-ear, right-ear, and diotic binaural word recognition in noise? and (2) How does recognition performance vary by age group?

Past related studies have shown that older adults with hearing loss and binaural interference may have more success using one hearing aid rather than two, and/or using an FM system rather than hearing aids alone (Carter et al., 2001; Chmiel et al., 1997). The results of the present study therefore may prove to be significant in several ways: (1) for clinical applications, by supporting certain future aural rehabilitation methods and (2) for research applications, by supporting past research and stimulating future research related to geriatric audiology.

CHAPTER 2

METHODS

Subjects

Two subject groups consisting of twelve individuals were recruited for the present study: six young adults with normal hearing, ages 18-30 years, and six older adults with sensorineural hearing loss, ages 60-89 years. To qualify as “normal hearing” individuals, young adults had pure tone thresholds of ≤ 20 dB HL for frequencies 250-8000 Hz and bone conduction thresholds within 10 dB HL of air conduction thresholds for frequencies 500-4000 Hz. Older adults had symmetric bilateral, sloping sensorineural hearing loss (air conduction thresholds within ± 10 dB HL between ears for frequencies 500-4000 Hz). Air conduction thresholds for the older adult group did not exceed 30 dB HL at 500 Hz and 70 dB HL at 4000 Hz. Air conduction and bone conduction thresholds were within ± 10 dB HL to ensure that hearing loss was sensorineural. To verify normal cognitive functioning abilities in the older adult subjects, a score of ≥ 25 was required on the Mini-Mental State Examination (Folstein et al., 1975).

Some studies have demonstrated that the REA may vary with handedness; right-handed people typically possess stronger REAs and seem to have less inter-subject variability than left-handed people (Wilson & Leigh, 1996). In attempt to account for this variability, only right-handed individuals were recruited. Right-handedness was validated for all subjects by the Edinburgh Handedness Inventory, which asks subjects to rate their hand preference(s) for ten common tasks (Oldfield, 1971).

Additionally, all subjects were checked for normal otoscopy (no drainage, impacted cerumen, etc.); no history of ear infections; normal tympanometric measures; no history of ototoxic medications; and generally good overall health. All subjects were native speakers of

American English. Subjects were recruited from The Ohio State University student population, The Ohio State University Hearing Clinic, and the greater community of Columbus, OH.

Stimuli

Two types of speech-recognition assessments were used: (1) monaural and diotic binaural word recognition in noise and (2) dichotic listening tasks. For both types of assessments, the Northwestern University Auditory Test No.6 (NU-6) monosyllabic words spoken by a female speaker from the Department of Veterans Affairs compact disc *Speech Recognition and Identification Materials 1.1* (VA Medical Center, Long Beach, CA, 1991) were used. NU-6 words are monosyllabic phonetically-balanced words commonly used in clinical audiology to measure speech understanding.

A two-channel CD recording of 100 NU-6 dichotic word pairs were used to measure dichotic word recognition (Roup et al., 2006). Specifically, individual NU-6 words were paired so that the presentation of the carrier phrase ‘say the word’ and the NU-6 words occurred essentially simultaneously on the two channels. Word pairings with similar initial and final consonants were avoided. Similarly, a two-channel CD recording of the 200 NU-6 words and multitalker babble was used to measure monaural and binaural word recognition performance. Specifically, six randomizations of the NU-6 word lists were generated and recorded on channel 1 with the multitalker babble recorded on channel 2 of the CD. The multitalker babble is a 6-talker babble consisting of three men and three women (Sperry et al., 1997). The interstimulus interval for both the dichotic words and word in multitalker babble was 4.5 seconds.

Procedures

Subjects participated in two sessions of 1 hour each consisting of two experimental conditions: dichotic word recognition and word recognition in multitalker babble. For the

dichotic listening tasks, the subjects responded in three response conditions: 1) free recall (repeat both stimuli in any order); 2) directed recall-right (repeat the stimulus from the right ear, followed by the stimulus from the left ear); and 3) directed-recall left (repeat the stimulus from the left ear, followed by the stimulus from the right ear). For each subject, free-recall was presented first in order to prevent subject's employing a specific listening strategy. The directed recall conditions (right and left) were presented after the free-recall condition and were counterbalanced across subjects. A minimum of five practice trials were given in order to familiarize the subject with each response condition. No feedback was provided, but verbal encouragement was given.

For word recognition in multitalker babble, the subjects responded in three response conditions: 1) monaural left; 2) monaural right; and 3) diotic binaural. In order to create a psychometric function [performance in percent by signal-to-babble ratio (SBR)], words were presented at five SBRs for both subject groups. For the young adult group, SBRs ranged from -4 dB SBR to +12 dB SBR in 4 dB steps. For the older adult group, SBRs ranged from +4 dB SBR to +20 dB SBR in 4 dB steps. For both subject groups, the level of the words was held constant while the level of the multitalker babble was varied to create the various SBRs. A list of 25 words was presented twice at each SBR, once on a descending run and once on an ascending run for a total of 50 words per SBR. The presentation order of each response condition and ascending/descending run were counterbalanced across subjects.

The experimental speech stimuli were routed from a CD player (Sony CE375) to a 2-channel audiometer (Grason Stadler 61) and presented via Etymotic ER-3A insert earphones. For both speech measures, the presentation level was 50 dB HL for the young adult group and 80 dB HL for the older adult group. All experimental testing was conducted in a sound-attenuating

booth. The testing equipment (audiometer and tympanometer) was calibrated according to the appropriate American National Standards Institute (ANSI) standards (ANSI, 2004, 1987) at the beginning of the study and at subsequent 6-month intervals. Biologic checks were conducted daily to confirm that the equipment continued to properly function.

CHAPTER 3

RESULTS

Descriptive Statistics

Table 1 displays group means (and standard deviations) for both young and older adults for the word recognition in multitalker babble task. Figure 1 also displays mean word recognition performance, showing psychometric functions for all SBR for both subject groups across all response conditions (right, left and binaural). As expected, young adults outperformed older adults at all common SBR across all listening conditions. Additionally, overall recognition performance was similar for the left and right monaural conditions for both subject groups, and the binaural condition always resulted in the best performance for each SBR. The 50%-correct thresholds were similar for the right and left ears for both groups. Specifically, the 50%-correct thresholds were 1.74 and 2.13 dB SBR for the right and left ears (respectively) for the young adult group, and 11.19 and 11.46 dB SBR for the right and left ears (respectively) for the older adult group. For both of these groups, the binaural 50%-correct threshold (0.83 and 8.67 dB SBR for young and older adults, respectively) was lower than both monaural conditions, indicating better recognition performance in the binaural condition.

Table 2 displays group means for the dichotic word recognition task across all response conditions. The young adult group exhibited better overall dichotic word recognition performance relative to the older adult group across all response conditions. To calculate the ear advantage (EA), the percent correct for the left ear was subtracted from the percent correct from the right ear. Resultantly, a positive EA would indicate a REA, and a negative EA would indicate a LEA. The EA's across response conditions for both subject groups are displayed as boxplots in Figure 2. The boxplot boundaries represent the 25th (lower boundary) and 75th (upper boundary)

Table 1. Mean word recognition performance (in percent correct) and standard deviations for both young and older adult groups at all SBRs across all response conditions (monaural right, left, and binaural).

		Signal-to-Babble Ratios						
		-4 dB	0 dB	4 dB	8 dB	12 dB	16 dB	20 dB
<u>Young Adults</u>								
Right Ear								
Mean		13.67	40.33	66.00	79.00	88.33		
SD		3.44	5.85	2.83	11.01	5.43		
Left Ear								
Mean		16.00	36.00	63.33	74.33	86.33		
SD		5.37	9.21	6.77	6.62	5.57		
Binaural								
Mean		25.00	45.00	67.00	82.33	92.00		
SD		6.90	7.46	3.74	6.62	3.79		
<u>Older Adults</u>								
Right Ear								
Mean				16.67	34.33	52.33	72.00	73.00
SD				5.61	7.31	7.31	7.90	14.24
Left Ear								
Mean				17.00	34.00	53.33	72.33	79.33
SD				8.92	12.46	15.27	14.11	12.50
Binaural								
Mean				22.67	45.67	66.33	76.67	85.67
SD				10.48	12.74	5.72	8.36	5.13

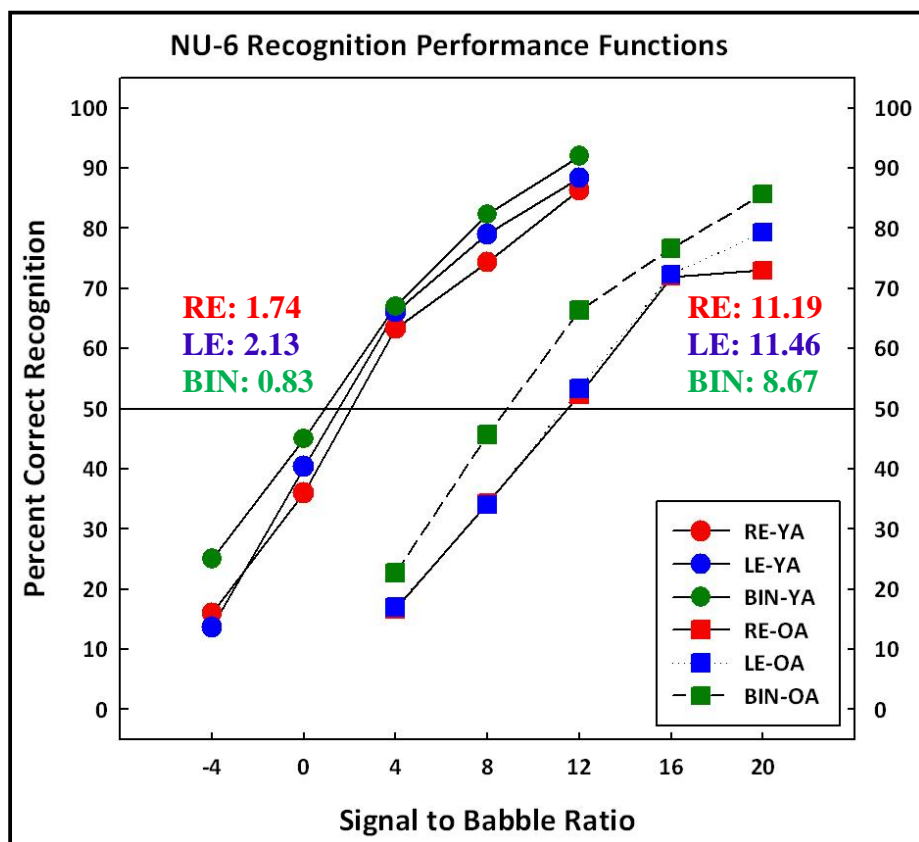


Figure 1. Psychometric functions for mean NU-6 recognition (percent correct) for SBR -4 and 20 dB for young adults (YA) and older adults (OA) across three response conditions: monaural right, monaural left and binaural. 50%-correct thresholds are listed near the 50%-correct line for each subject group.

Table 2. Mean dichotic word recognition performance (in percent correct) and standard deviations for young and older adults across all response conditions: free recall, directed right and directed left.

	Right Ear	Left Ear	RE-LE (Ear Advantage)
<u>Young Adults</u>			
Free Recall			
Mean	81.67	83.67	-1.00
SD	9.33	10.27	9.36
Directed Right			
Mean	85.67	82.67	3.00
SD	3.44	6.41	3.52
Directed Left			
Mean	83.00	88.33	-5.33
SD	7.24	4.27	6.53
<u>Older Adults</u>			
Free Recall			
Mean	63.33	65.33	1.00
SD	11.64	16.81	12.51
Directed Right			
Mean	72.67	61.67	11.00
SD	16.62	15.51	26.28
Directed Left			
Mean	56.67	75.33	-18.67
SD	15.00	10.71	10.33

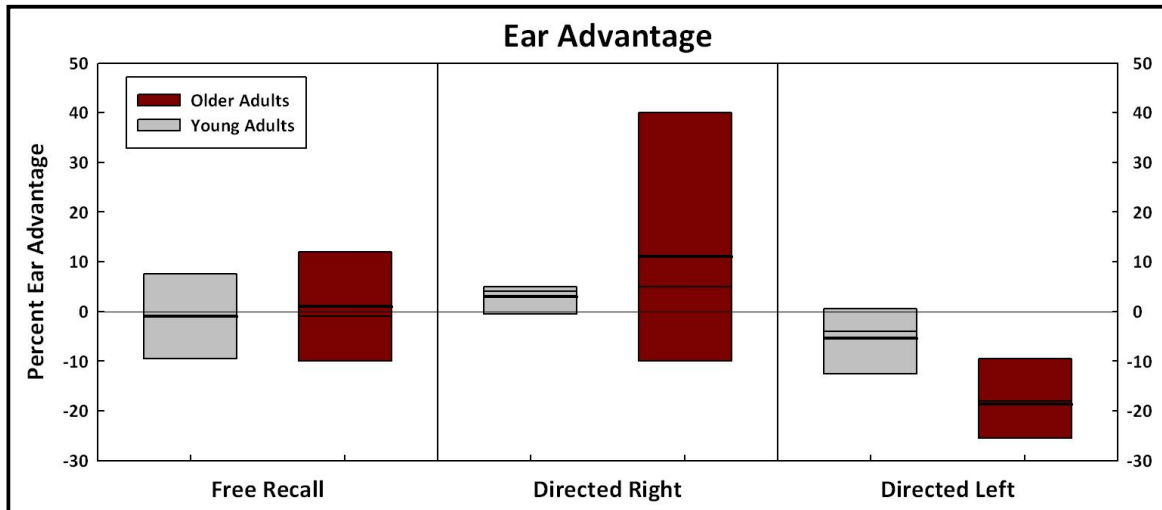


Figure 2. Mean ear advantages (in percent) for young and older adults across the three dichotic response conditions: free recall, directed right, and directed left. (Medians for each box plot are indicated by the thin black line; means are indicated by the thick black line.)

percentiles with the means represented by the thick black line and the medians represented by the thin black line. The young adult group mean in the free recall condition shows an overall slight LEA (-1% EA), whereas older adults exhibited a slight mean REA (1% EA). As expected, the directed response conditions resulted in increased ear advantages for both sides: directed right resulted in larger REAs (3% EA for young adults and 11% EA for older adults), and directed left correspondingly resulted in larger LEAs (-5.33% EA for young adults and -18.67% EA for older adults).

Statistical Analysis

Prior to statistical analysis, all percentage data were transformed to rationalized arcsine units (raus) in order to address the error in variance associated with percentage data (Studebaker, 1985). In order to determine if significant differences in word recognition performance existed across response conditions, the 50%-correct thresholds were compared using a series of t-tests of means. For the young and older adult groups, results revealed no significant difference in word recognition performance between right and left ears. Subsequently, recognition performance for the right and left ears were combined and then compared to binaural performance for 50%-correct thresholds. Results revealed significant differences in recognition performance for both young and older adult groups between monaural and binaural conditions (young adults: $t_{10} = 2.3$; $p < .05$; older adults: $t_{10} = 2.4$; $p < .05$). Specifically, binaural recognition performance was significantly better than monaural recognition performance for subject groups at 50%-correct thresholds. Similarly, a series of t-tests of means was used to determine if significant differences in the 50%-correct thresholds existed between subject groups. Results revealed significant differences in recognition performance for the right ear ($t_{10} = -18.9$; $p < .05$), left ear ($t_{10} = -7.4$; p

< .05) and binaural conditions (-9.6). Specifically, the young adult group performed significantly better than the older adult group across all response conditions.

A series of t-tests for means was also conducted to determine significance for the dichotic word recognition task. For t-tests *within* both subject groups, results revealed no significant difference in dichotic word recognition performance between right and left ears across all response conditions (free recall, directed right, and directed left). EAs were then compared *across* subject groups in all response conditions. Results showed there were no significant differences between young adult and older adult EAs in the free recall and directed right conditions, but there was a significant difference in group mean performances for the directed left condition ($t_{10} = -2.3$; $p < .05$). Specifically, the older adults showed a significantly larger negative EA, indicating a larger LEA for the directed left condition.

Individual Results

Older adults showed considerable variation in their responses for both tasks. To demonstrate this subject-to-subject variability, recognition performance data from two subjects are displayed in Figures 3 and 4. Each figure shows a different pattern of performance between and across the two experimental measures. Figure 3, a 68 year old female, shows a “typical” pattern of performance, or a performance that parallels the overall mean group data. For the dichotic listening task, this subject exhibited a slight REA for the free recall condition, an increased REA for the directed right condition, and a LEA for the directed left condition. For the word recognition in multitalker babble task, this subject performed better in the binaural condition than in either monaural condition at all SBRs, and both monaural condition recognition performances were similar.

Figure 4 shows data for a 76 year old male, a subject who exhibits “atypical” results, or an unexpected pattern of performance. This subject showed a LEA for all response conditions of the dichotic listening task, even when the subject was directed to his right side. For the word recognition in multitalker babble task, the subject consistently performed better in the monaural left than the monaural right condition. Furthermore, the subject did not consistently exhibit better recognition performance in the binaural condition. In fact, the subject showed better recognition performance for the monaural left condition than the binaural condition for some SBRs.

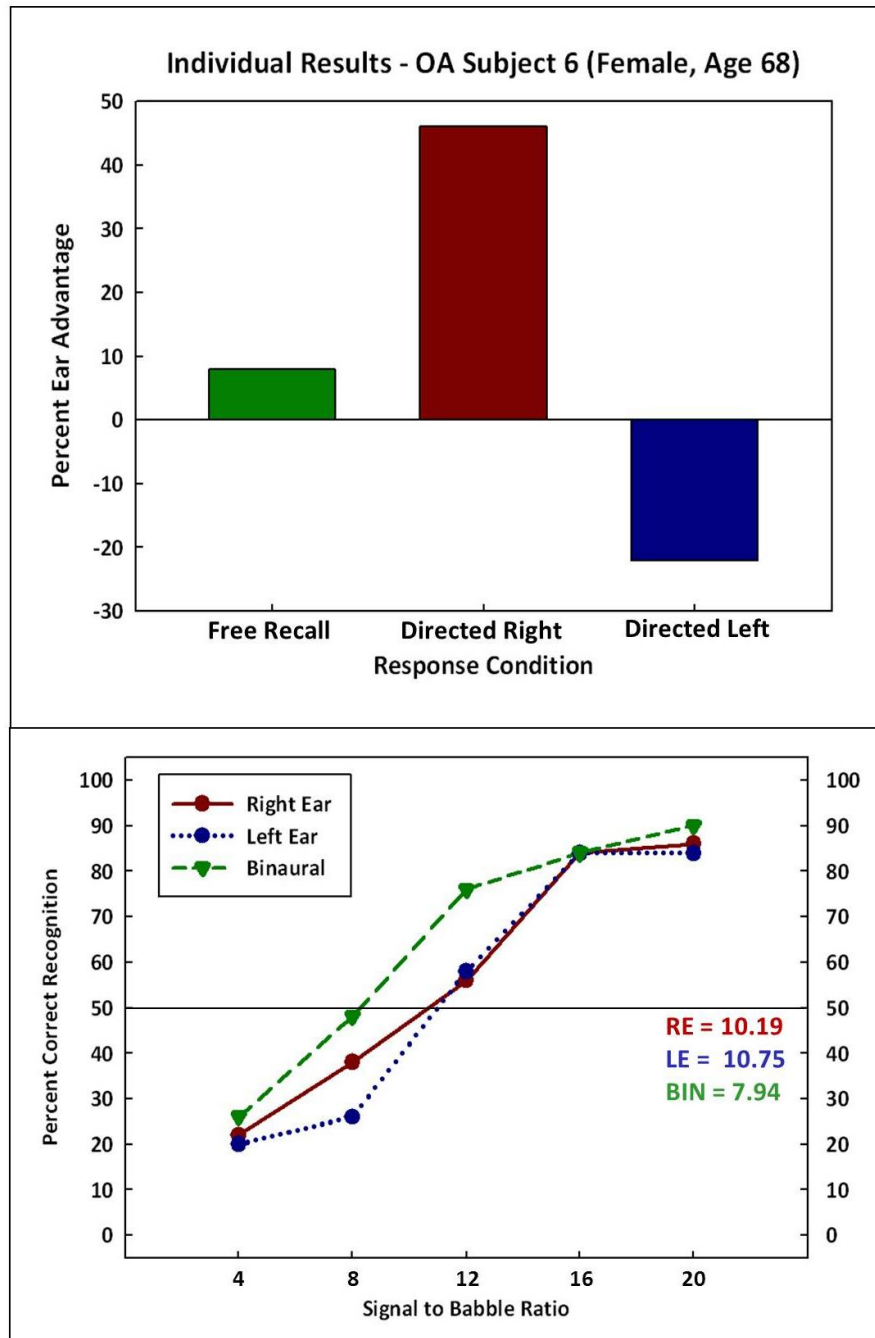


Figure 3. Individual data for dichotic word recognition (top graph) and the word recognition in multitalker babble (bottom graph) for a 68 year old female. This subject exhibited “typical” results for each task, specifically: (1) a slight REA for free recall, larger REA for directed right, and a LEA for directed left; and (2) better recognition performance in the binaural condition compared to right and left monaural conditions for all SBRs and similar right and left monaural recognition performance.

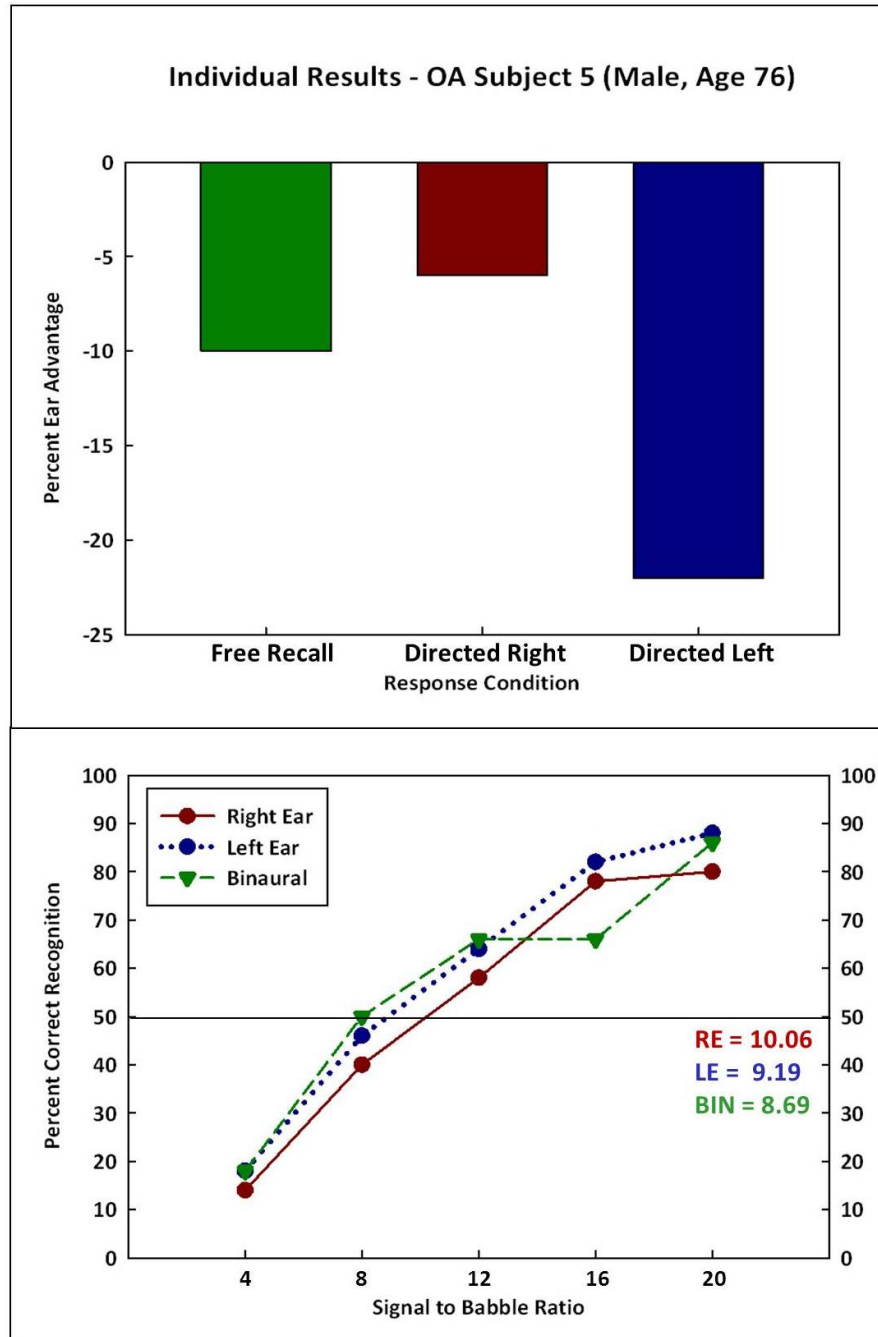


Figure 4. Individual data for dichotic word recognition (top graph) and the word recognition in multitalker babble (bottom graph) for a 76 year old male. This subject exhibited “atypical” results for each task, for example: (1) a LEA for *all* dichotic response conditions; and (2) consistently better left ear recognition performance compared to right ear for all SBRs and no consistent binaural advantage.

CHAPTER 4

DISCUSSION

The present study aimed to assess monaural and binaural processing abilities among young adults with normal hearing and older adults with sensorineural hearing loss by using two types of speech recognition tasks. Specifically, the present study asked two central questions: (1) When examining word-recognition performances of young and older adults, what is the relationship between dichotic listening and left-ear, right-ear, and diotic binaural word recognition in noise? and (2) How does recognition performance vary by age group?

The relationship between dichotic word recognition and word recognition in noise lies in the patterns of performance. By comparing word recognition performance across response conditions, it can be determined whether or not the subject (or groups of subjects) performed typically (i.e., exhibiting a binaural advantage) or atypically (i.e., not exhibiting a binaural advantage). Further, dichotic word recognition tasks assist in determining EAs when the subject is given (or not given) a specific listening strategy. Results of both the word recognition in noise and dichotic word recognition tasks can then be compared to see if the subject (or group) performs better binaurally or monaurally in competitive listening environments.

Group performance for young and older adults on the word recognition in multitalker babble task resulted in the expected patterns of performance. Specifically, both groups exhibited similar recognition performance between right and left ears, with best recognition performance in the binaural condition at all SBRs. This indicates that both groups exhibited a binaural advantage. Additionally, for both young and older adults, the 50%-correct thresholds on the word recognition psychometric functions were comparable for right and left ears (young adults: RE 1.74 dB SBR, LE 2.13 dB SBR; older adults: RE 11.19 dB SBR, LE 11.46 dB SBR), showing

there was no significant difference in performance when listening with either ear alone. The 50%-correct threshold for the binaural condition, however, was significantly lower for both subject groups (young adults: 0.83 dB SBR, older adults: 8.67 dB SBR), pointing to better recognition performance when listening with two ears (i.e., a binaural advantage).

When comparing young adult to older adult recognition performance, two overall key conclusions can be made. First, the young adults performed better than the older adults across all common SBRs. The 50%-threshold was achieved at a significantly lower SBR for the young adults (0.83 dB SBR) relative to the older adults (8.67 dB SBR), suggesting that older adults with sensorineural need approximately an 8 dB improvement in the signal to noise ratio for comparable recognition performance. This difference in performance can be explained by the differences in hearing sensitivity between the two groups, namely the presence of sensorineural hearing loss in the older adults.

Another key conclusion that can be gathered from the word recognition in noise data is the degree of separation between the binaural condition and monaural conditions for each group. When looking at Figure 1, it is evident that this separation is greater for older adults than young adults. The larger separation indicates an increased difference between binaural and monaural recognition performance, or a larger binaural advantage. Additionally, the separation in recognition performance for the older adults between the binaural and the two monaural listening conditions was most evident at the mid signal-to-babble ratios (8 – 12 dB SBRs) near the 50%-threshold (8.67 dB SBR). It can be concluded then, based on this data, that as a person ages, the difference between his/her binaural and monaural speech recognition ability increases, especially in listening environments of intermediate difficulty (those in the middle part of the psychometric

function). More specifically, binaural listening becomes more important to speech understanding in difficult listening environments for older listeners with sensorineural hearing loss.

For the dichotic listening task, it was hypothesized that the young adults would exhibit larger ear advantages for the directed attention conditions relative to the free recall condition: an increased REA for the directed right condition, and a LEA for directed left. As expected, the young adult group exhibited a REA in the directed right condition (3.0% EA) and a LEA in the directed left condition (-5.3% EA), both greater than the free recall EA (-1.0% EA). Similarly, the older adult group exhibited a larger REA in the directed right condition (11.0% EA), and a LEA in the directed left condition (-18.7% EA), also both larger EAs compared to the free recall condition (1.0% EA). These results support past research findings for directed attention conditions – specifically, that directing the subject to attend to a certain side provides the subject with a listening strategy, thereby reducing cognitive demands of the task and increasing recognition performance for words presented to that ear (Carter et al., 2001).

Kimura (1961) showed that most people lateralize language in the left hemisphere. Additionally, the contralateral pathways of the auditory system are more effective in relaying speech signals than ipsilateral pathways. Stimuli presented to the left ear must therefore first be relayed to the right hemisphere, then cross the corpus callosum to be processed in the left hemisphere. Resultantly, when given no listening strategy, materials presented to the right ear will be better recognized in difficult listening environments than stimuli presented to the left ear. Although the young adults showed the expected overall pattern of performance for dichotic listening, they did unexpectedly exhibit a small mean LEA in the free recall condition (-1.0% EA). Similarly, the older adult group exhibited the overall expected pattern of performance: a small REA in the free recall condition (1.0% EA), a larger REA in the directed right condition

(11.0% EA), and a LEA in the directed left condition (-18.7% EA), but the magnitude of the REA in the free recall condition was smaller than expected. The present study differs from past research in that past related studies report mean REAs for young adults and exaggerated mean REAs for older adults with hearing loss in free recall (Carter et al., 2001; Jerger & Jordan, 1992; Roup et al., 2006). The reduced magnitudes of group means in the free recall condition for the present study are likely attributable to the small sample size and high subject-to-subject variability.

Individual older adult data reflected this variability quite considerably. The boxplots in Figure 2 and the standard deviations for older adult data show that older adults were much more variable in their performances than young adults for both speech recognition tasks. Individual results of two adult subjects, one exhibiting a “typical” pattern of performance and one exhibiting an “atypical” pattern of performance are highlighted in the Results section (Figures 3 and 4). The older adult whose data reflects a “typical” pattern of performance showed a slight REA for the free recall condition, an increased REA for directed right, and a LEA for directed left. Further, this subject exhibited better performance in the binaural condition when compared to both monaural conditions, indicating a binaural advantage. The subject who showed an “atypical” pattern of performance showed a LEA for all dichotic listening conditions, even when directed to his right side. In addition, this subject showed no real binaural advantage, and he consistently performed better in the monaural left condition than in the monaural right. What can be concluded from these individual results is that, even though the group means may reflect expected results, the range of variability from subject to subject shows that not all perform as anticipated. Recognition performance particularly varies in older adult subjects, some who may not be exhibiting “typical” results (i.e., results contraindicating a binaural advantage).

Clinical Implications and Future Research

The data from the present study suggests that the majority of older adult listeners perform best when listening binaurally in competing listening situations. The study has shown, however, that older adults tend to be more variable in their speech recognition abilities. Further, some older adults exhibit atypical recognition performance that is not consistent with a binaural advantage. For these individuals, traditional rehabilitation strategies (i.e., binaural amplification) may not be beneficial, especially those exhibiting binaural processing deficits (i.e., binaural interference). Past related studies have shown that older adults with hearing loss who exhibit signs of binaural interference may have more success using one hearing aid rather than two, and/or using an FM system rather than hearing aids alone (Carter et al., 2001; Chmiel et al., 1997). Jerger et al. (1993) approximate that the prevalence of binaural interference to be approximately 8 to 10 percent among older adults with hearing aids. The data from the present study support the use of binaural diagnostic word recognition measures to identify these older adults who, despite symmetric pure-tone thresholds, may lack a true binaural advantage and may benefit better from a non-traditional monaural hearing aid fitting.

The results of the present study may also prove to be significant for research applications, by supporting past research and stimulating future research related to geriatric audiology. One primary weakness of the present study was the small sample size in both subject groups (6 young adults, 6 older adults). Future research could expand the number of participants and also could focus on comparing speech recognition results across specific age ranges (i.e., 60-70 years, 71-80 years, 81-90 years). The present study showed a high degree of variability in speech recognition ability among older adults. If this variability is attributable to the aging process,

examining older adult recognition performance in specific age ranges could prove to be beneficial.

Another weakness of the present study was its limitation in terms of handedness information. The present study only examined monaural and binaural processing abilities of right-handed individuals, mainly due to the higher variability reported among left-handers for these tasks (Wilson & Leigh, 1996) combined with limited time and resources for the study. Future research could focus more on including left-handed individuals in binaural speech recognition studies, along with examining the differences between right- and left-handers for different speech recognition tasks (i.e., word recognition in noise and dichotic listening).

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REFERENCES

- Allen, R.L., Schwab, B.M., Cranford J.L., & Carpenter, M.D. (2000). Investigation of binaural interference in normal-hearing and hearing-impaired adults. *Journal of the American Academy of Audiology*, 11(9), 494-500.
- American National Standards Institute. (1987). *Specification for instruments to measure aural acoustic impedance and admittance (aural acoustic immittance)*. (ANSI S3.39-1987 R2002). New York: ANSI.
- American National Standards Institute. (2004). *Specification for audiometers* (ANSI S3.6-2004). New York: ANSI.
- Bellis, J.T., & Wilber, L.A. (2001). Effects of aging and gender on interhemispheric function. *Journal of Speech, Language, and Hearing Research*, 44, 246-263.
- Bryden, M.P. (1979). Evidence for sex-related differences in cerebral organization. In M. Wittig & A.C. Petersen (Eds.), *Sex-related Differences in Cognitive Functioning: Developmental Issues*. New York: Academic Press.
- Bryden, M.P. (1988). An overview of the dichotic listening procedure and its relation to cerebral organization. Hugdahl, K., ed. *Handbook of Dichotic Listening: Theory, Methods and Research*. New York: Jon Wiley and Sons.
- Carter, A.S., Noe, C.M., & Wilson, R.H. (2001). Listeners who prefer monaural to binaural hearing aids. *Journal of the American Academy of Audiology*, 12, 261-272.
- Chmiel, R., Jerger, J., Murphy, E., Pirozzolo, F., & Tooley-Young, C. (1997). Unsuccessful use of binaural amplification by an elderly person. *Journal of the American Academy of Audiology*, 8, 1-10.
- Dubno, J.R., Lee, F.S., Matthews, L.J., & Mills, J.H. (1997). Age-related and gender-related changes in monaural speech recognition. *Journal of Speech, Language, and Hearing Research*, 40, 444-452.
- Folstein, M.F., Folstein, S.E., & McHugh, P.R. (1975). "Mini-Mental State": A practical method for grading the cognitive status of patients for the clinician. *Journal of Psychiatric Research*, 12, 189-198.
- Gelfand, S.A., Hoffman, S., Waltzman, S.B., & Piper, N. (1980). Dichotic CV recognition at various interaural temporal onset asynchronies: effect of age. *Journal of the Acoustical Society of America*, 68, 1258-1261.
- Grose, J.H. (1996). Binaural performance and aging. *Journal of the American Academy of Audiology*, 7, 168-174.

- Haggard, M., & Hall, J. (1982). Forms of binaural summation and the implications of individual variability for binaural hearing aids. *Scandinavian Audiology*, 15(Supp): 47-63.
- Hiscock, M. & MacKay, M. (1985). The sex difference in dichotic listening: Multiple negative findings. *Neuropsychologia*, 23: 437-440.
- Jerger, J., Silman, S., Lew, H.L., & Chmiel, R. (1993). Case studies in binaural interference: converging evidence from behavioral and electrophysiologic measures. *Journal of the American Academy of Audiology*, 4, 122-131.
- Jerger, J., & Jordan, C. (1992). Age-related asymmetry on a cued-listening task. *Ear & Hearing*, 13(4): 272-277.
- Kimura, D. (1961). Cerebral dominance and the perception of verbal stimuli. *Canadian Journal of Psychology*, 15(3), 166-171.
- Noffsinger, D. (1985). Dichotic-listening techniques in the study of hemispheric asymmetries. In: Benson DF, Zaide E, eds. *The Dual Brain*. New York: Guilford, 127-141.
- Noffsinger, D., Martinez, C.D., & Andrews, M. (1996). Dichotic listening to speech: VA-CD data from elderly subjects. *Journal of the American Academy of Audiology*, 7, 49-56.
- Oldfield, R.C. (1971). The assessment and analysis of handedness: the Edinburgh Inventory. *Neuropsychologia*, 9, 97-113.
- Roup, C. M., Wiley, T. L., & Wilson, R. H. (2006). Dichotic word recognition in young and older adults. *Journal of the American Academy of Audiology*, 17, 230-240.
- Sperry, J.L., Wiley, T.L., & Chial, M.R. (1997). Word recognition performance in various background competitors. *Journal of the American Academy of Audiology*, 8, 71-80.
- Studebaker, GA. (1985) A rationalized arcsine transform. *Journal of Speech and Hearing Research*, 28, 455-462.
- Warren, L. R., Wagener, J. W., & Herman, G. E. (1978). Binaural analysis in the aging auditory system. *Journal of Gerontology*, 33(5), 731-736.
- Wilson, R.H., & Jaffe, M.S. (2003). Development of a speech-in-multitalker-babble paradigm to assess word-recognition performance. *Journal of the American Academy of Audiology*, 14(9), 453-470.
- Wilson, R.H., & Leigh, E.D. (1996). Identification performance by right- and left-handed listeners on dichotic CV materials. *Journal of the American Academy of Audiology*, 7, 1-6.
- Yost, W.A. (2007). *Fundamentals of Hearing: An Introduction* (5th ed.). Oxford, UK: Elsevier Inc.